Charm-loop contribution from data

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on behalf of the LHCb collaboration

24/09/19

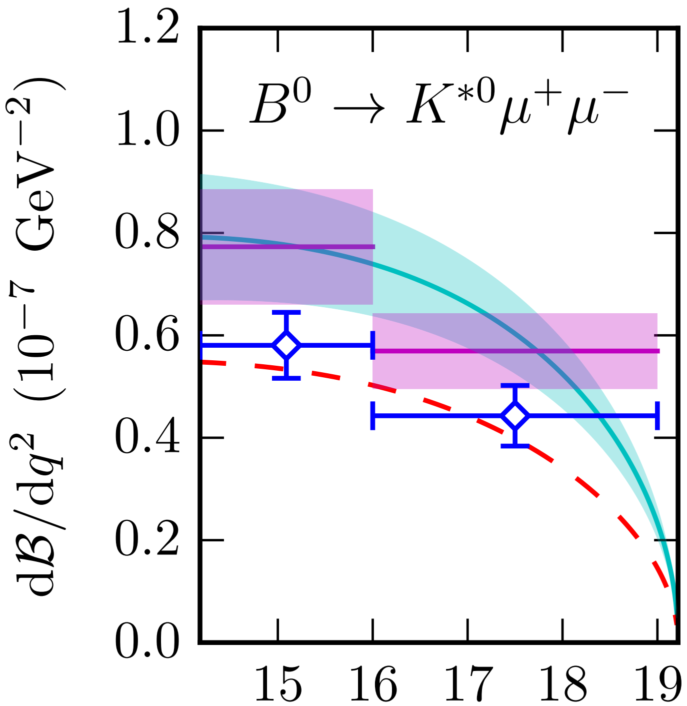
2nd Hadronic Contributions to New Physics
(HC2NP) workshop

Universität Zürich[UZH]

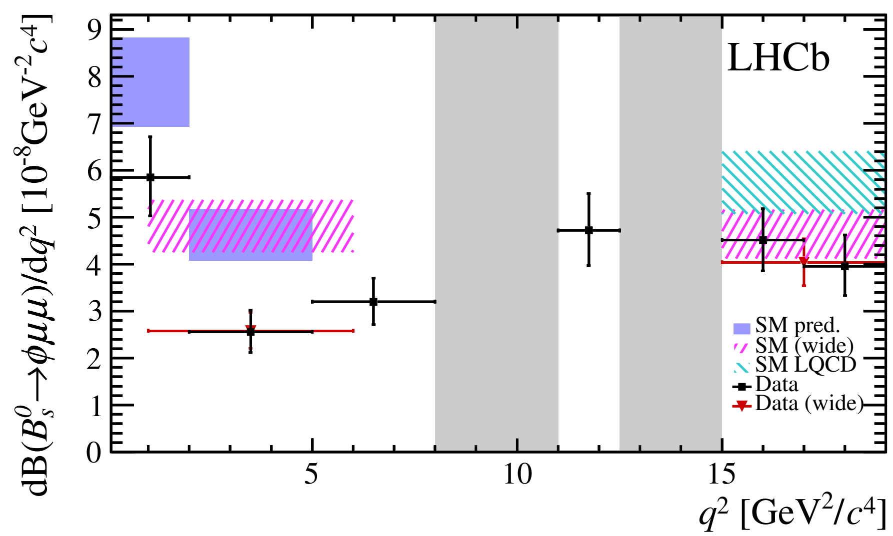
Tensions

Something is interfering with b—>sll decays.

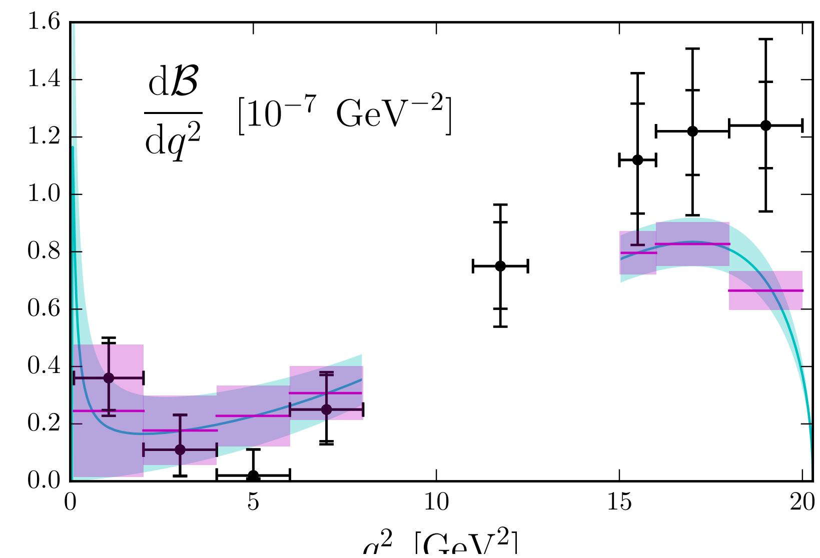
Phys. Rev. Lett. 112, 212003 (2014)



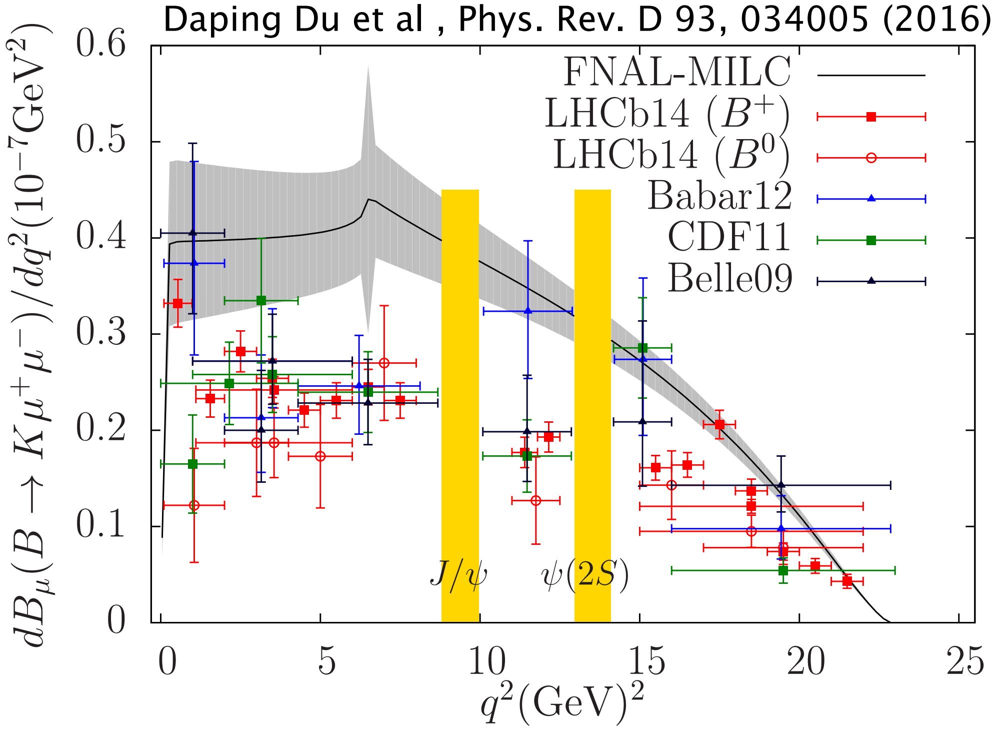
JHEP09(2015)179

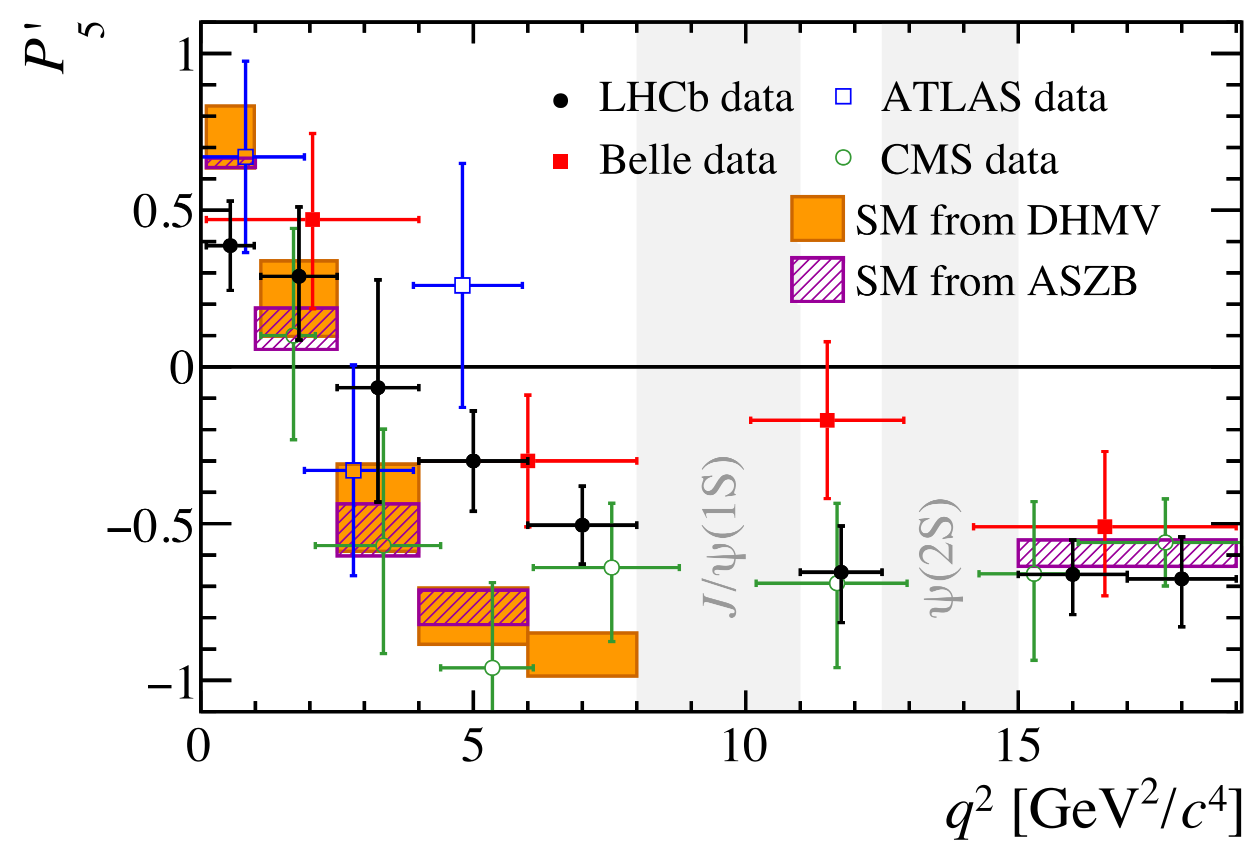


Phys. Rev. D 93, 074501 (2016)



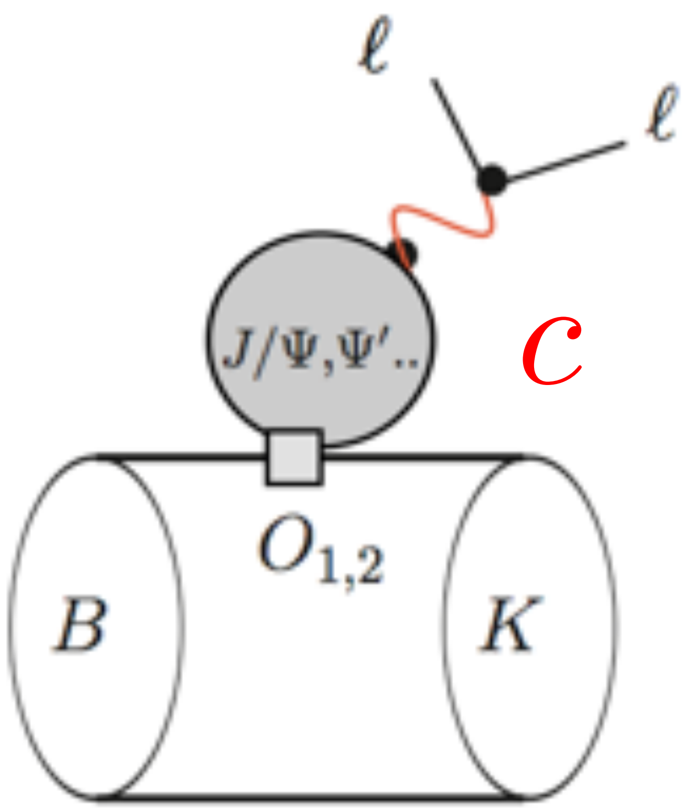
Daping Du et al , Phys. Rev. D 93, 034005 (2016)

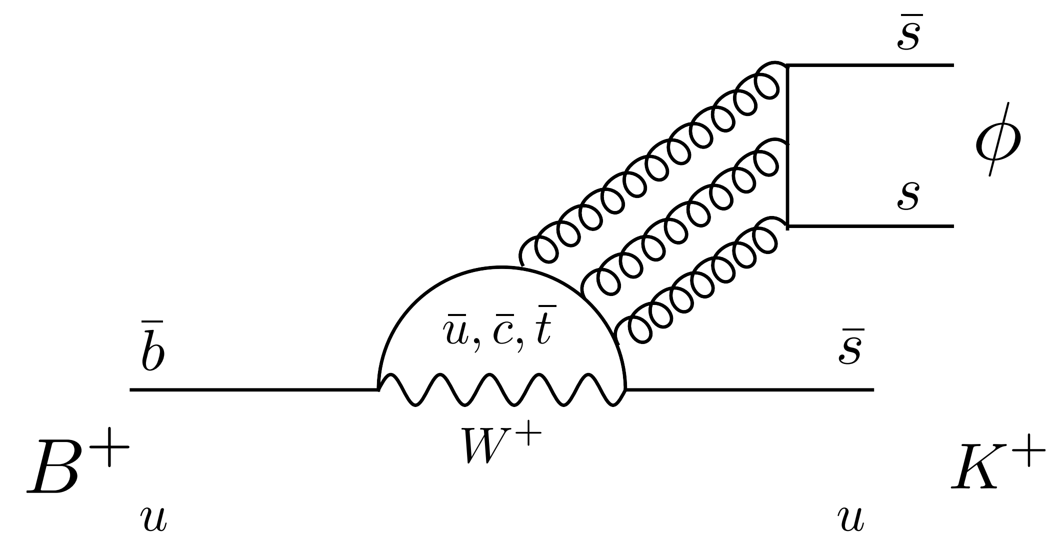




What am I talking about

Theoretically difficult to calculate



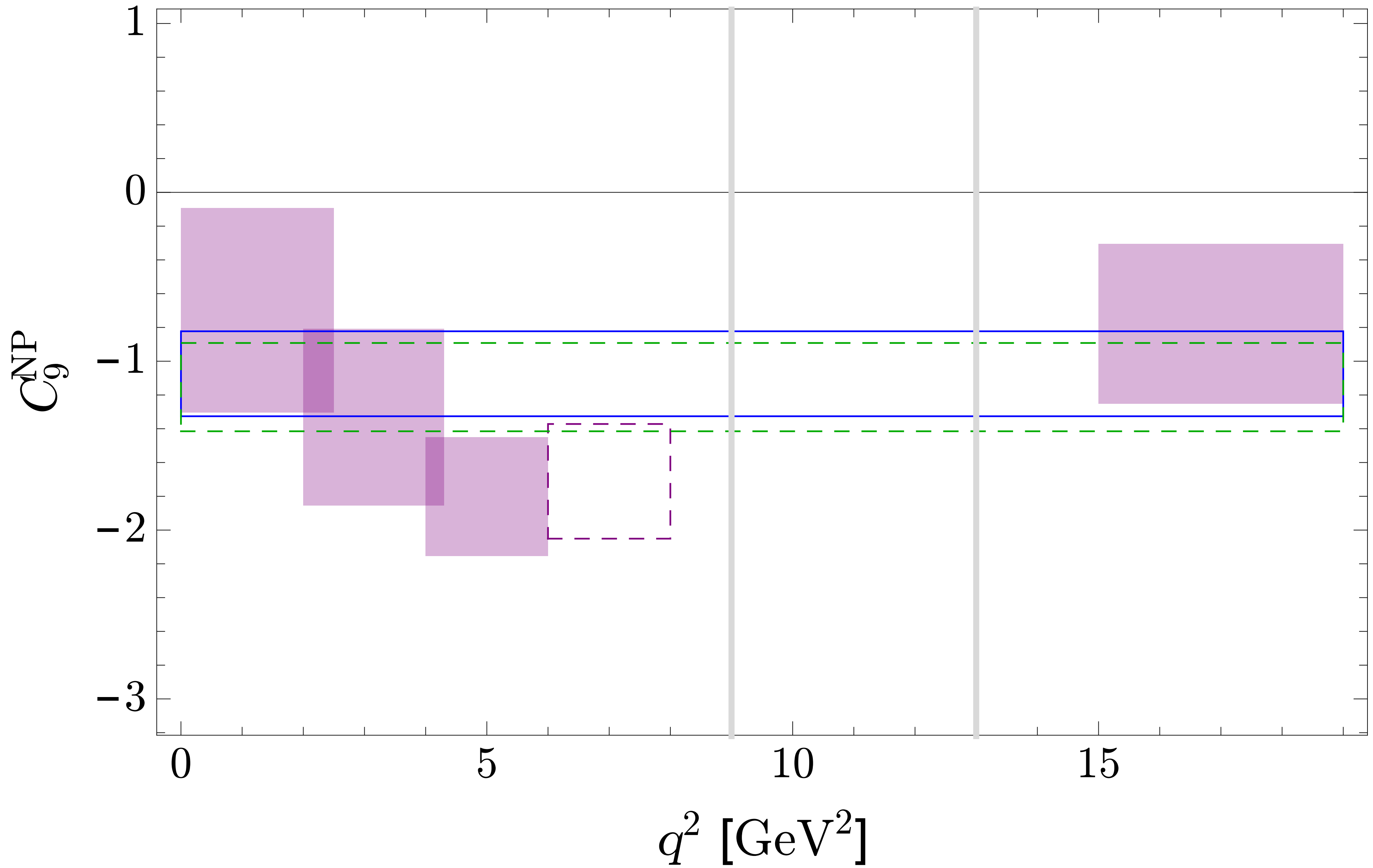


Could it be causing the tensions in previous slide?

Checks with data

- Can bin global fit in q^2.

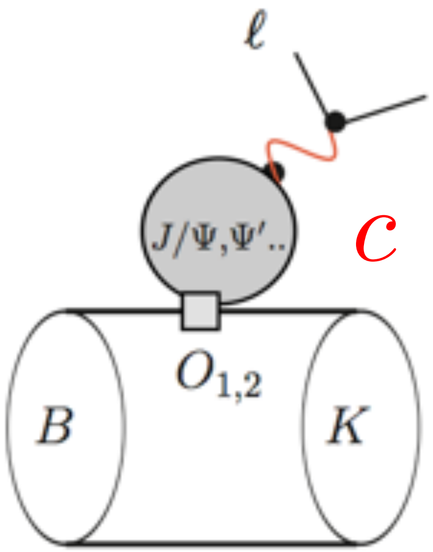
Altmanshofer, Straub, arXiv:1503.06199



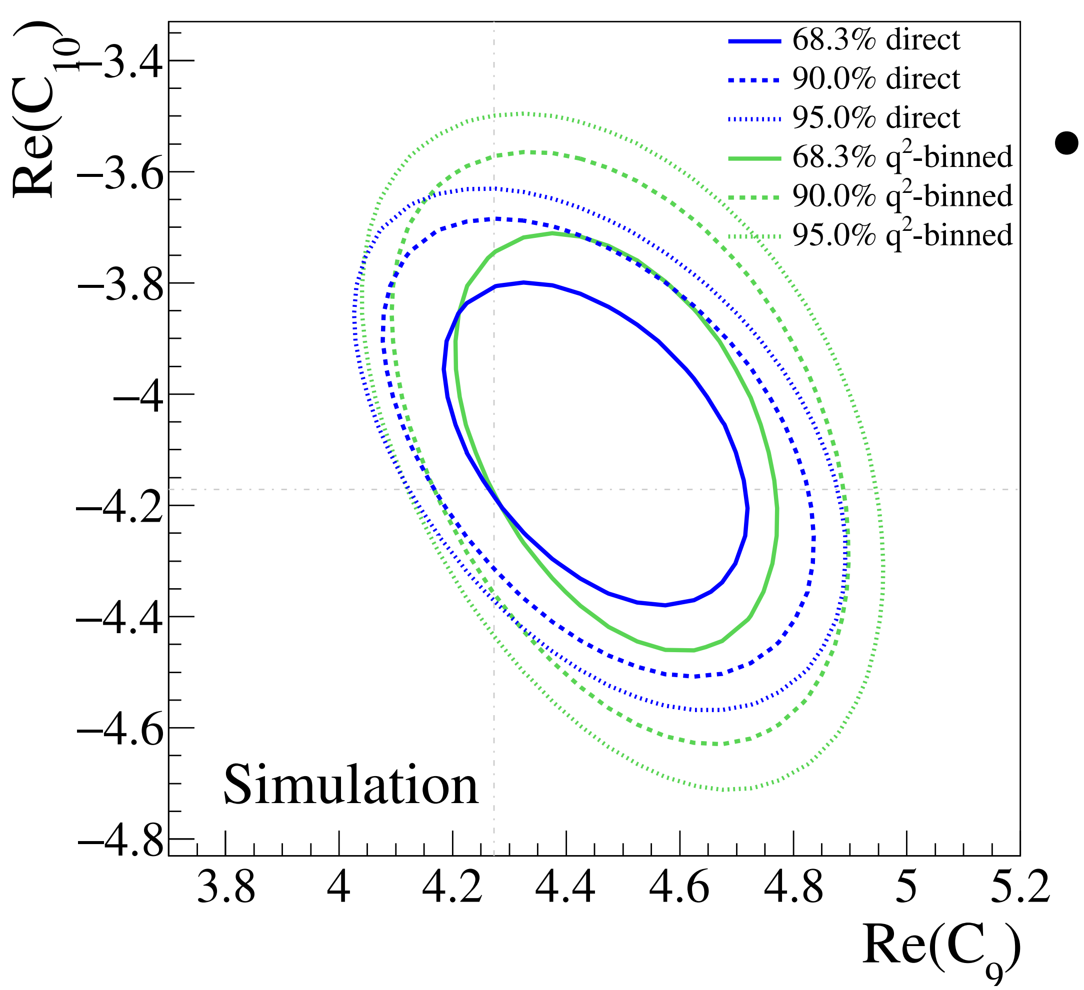
- No significance dependence seen with q^2.

The importance of an amplitude analysis

- Observables integrated in q^2 bins largely theory independent.
- However, important information in q^2 spectrum lost.
  - Useful to determine long-distance contributions.
  - Can also improve sensitivity to semileptonic part.



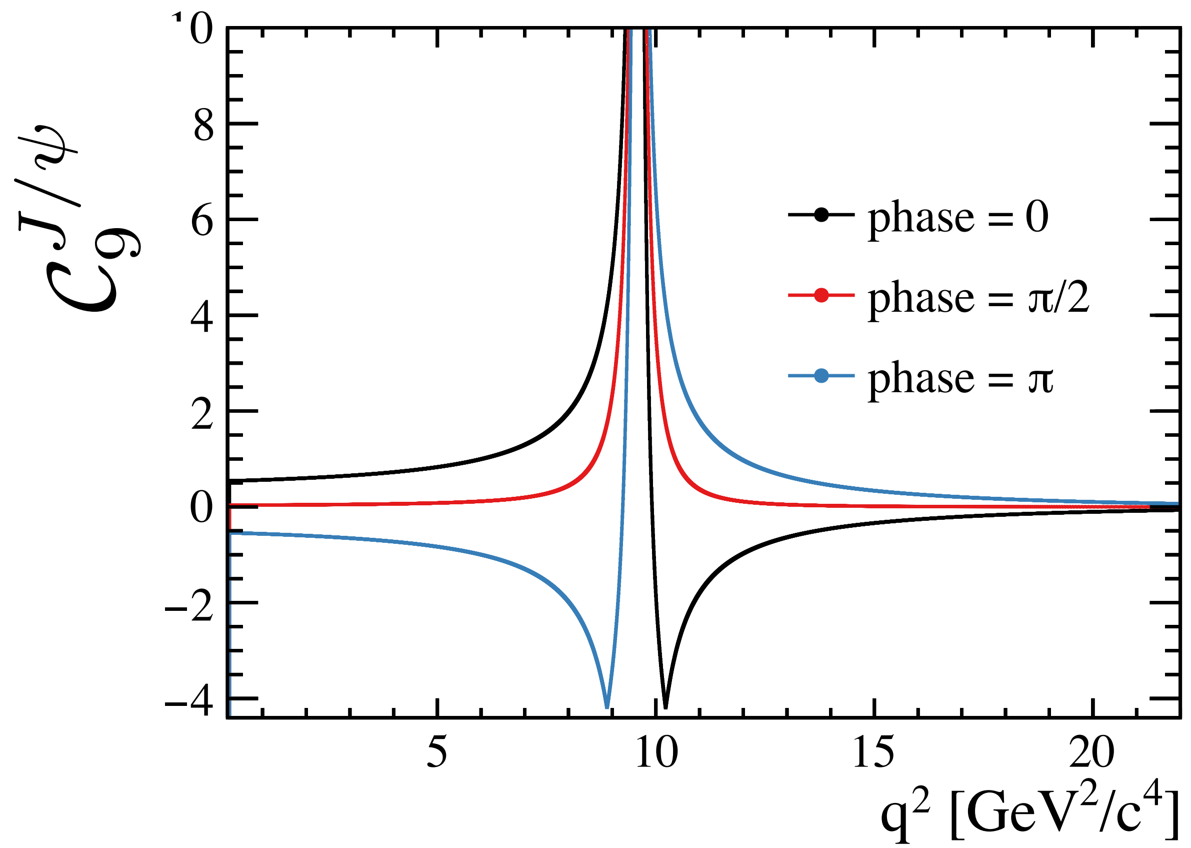
T. Hurth, C. Langenbruch, F. Mahmoudi

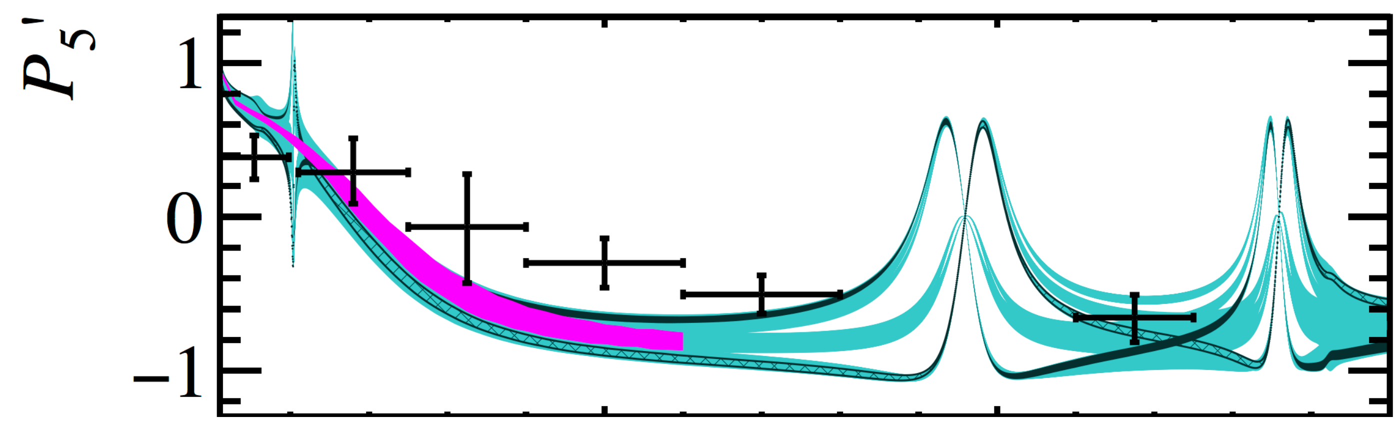


- Will discuss two approaches today:
  - **Isobar:** **LHCb, Eur. Phys. J. C (2017) 77: 161**
    Blake et al, Eur. Phys. J. C (2018) 78: 453
  - **z-expansion:** **Bobeth et al, Eur. Phys. J. C, 78 6 (2018)**
    Chrzaszcz et al, arxiv:1805.06378
    Mauri et al, Phys. Rev. D 99, 013007 (2019)

Isobar approach

- The idea that the J/ψ phase can have a large effect at low q^2 was first discussed in [1].





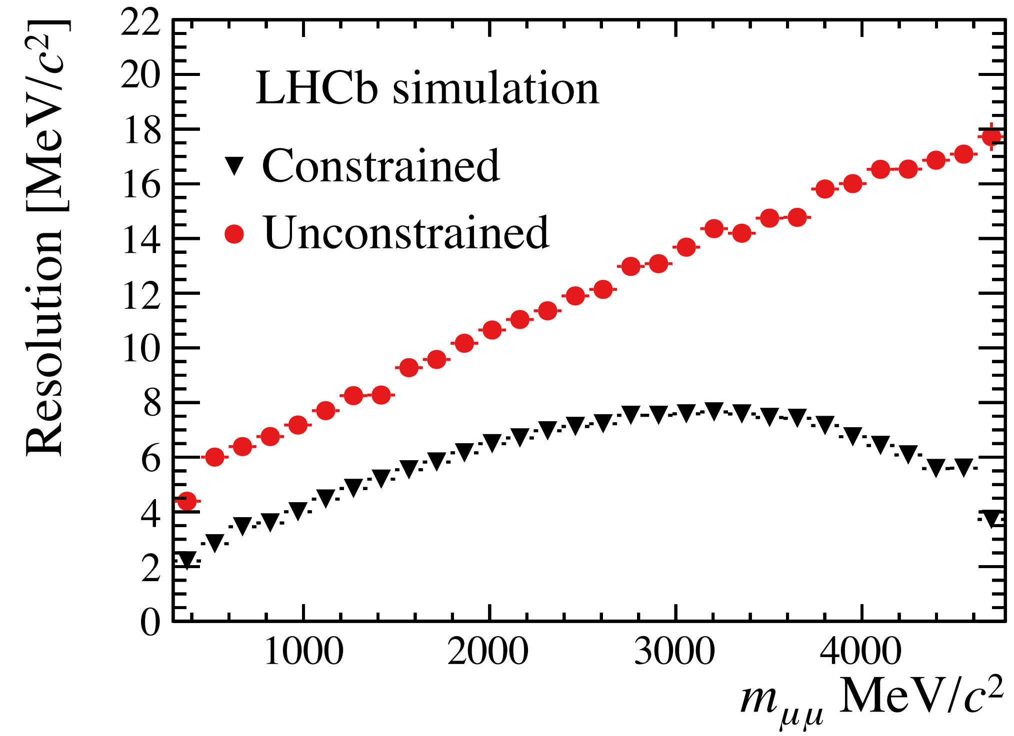
Blake et al, Eur. Phys. J. C (2018) 78: 453

- By modelling the resonances with Breit-Wigner functions, can determine these phases with the data.

[1] Lyon, Zwicky, arXiv:1406.0566

Experimental issue

- Main issue to deal with is the narrow J/psi and psi(2S) widths of 90 KeV and 300 KeV.
- Resolution 100 times larger than that.
- The other issue is that we have ~1M candidates at the J/psi peak.



- Phase sensitivity from its tail, where resolution is complicated.
  - Calculate q^2 after B-mass constrained kinematic fit.
  - Float resolution parameters when fitting for phase.
  - Validate fit with two different resolution approaches.

Fit model (Kμμ)

lepton mass term

phase-space

form factors

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2 \alpha^2 |V_{tb} V_{ts}^*|^2}{2^7 \pi^5} |\boldsymbol{k}| \beta_+ \left\{ \frac{2}{3} |\boldsymbol{k}|^2 \beta_+^2 \left| C_{10}^{\text{eff}} f_+(q^2) \right|^2 + \frac{m_l^2 (M_B^2 - M_K^2)^2}{q^2 M_B^2} \left| C_{10}^{\text{eff}} f_0(q^2) \right|^2 \right.$$
$$\left. + |\boldsymbol{k}|^2 \left[1 - \frac{1}{3} \beta_+^2 \right] \left| C_9^{\text{eff}} f_+(q^2) + 2 C_7^{\text{eff}} \frac{m_b + m_s}{M_B + M_K} f_T(q^2) \right|^2 \right\}, \qquad (2.10)$$

Add resonances here.

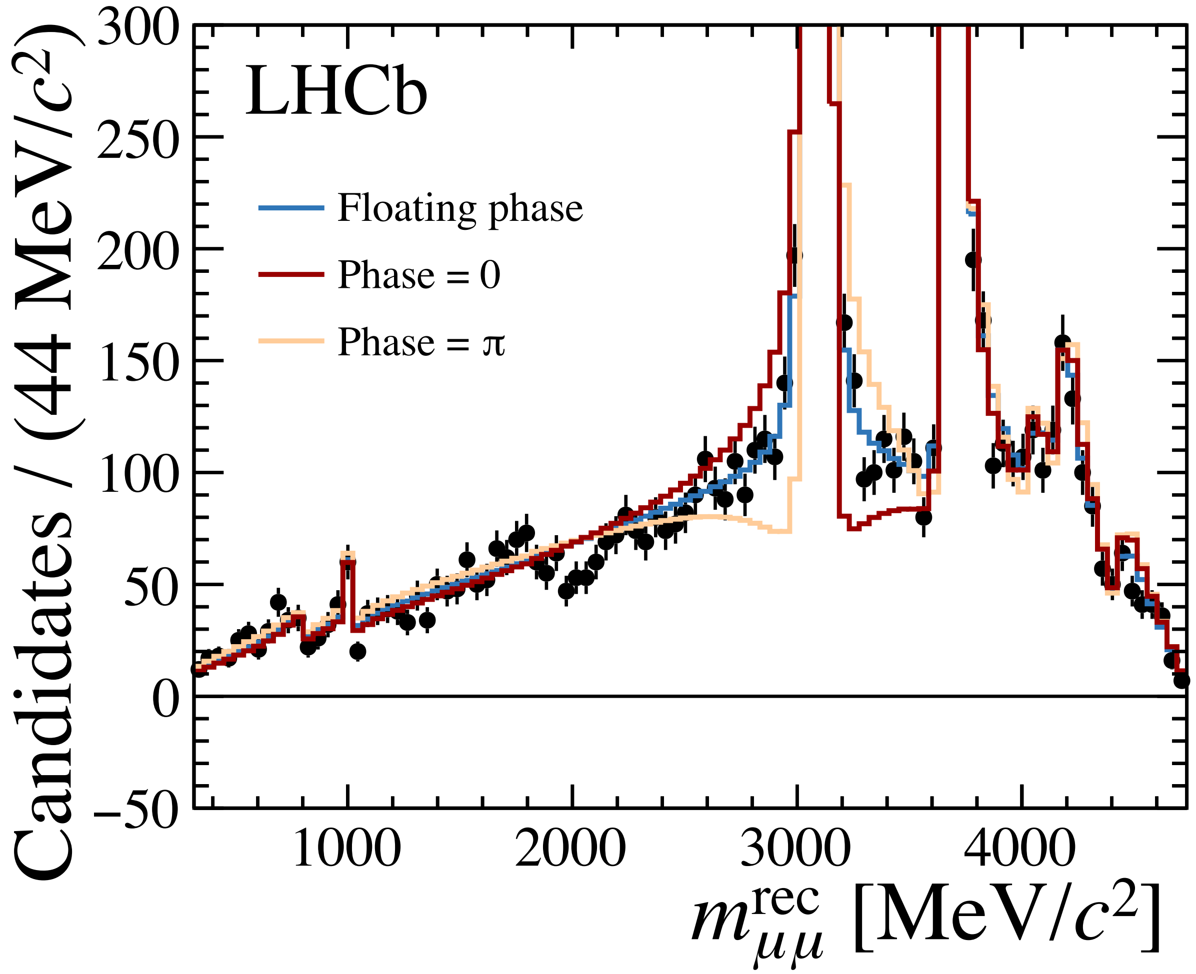
Replace Y(q2) term with sum of Breit-Wigner functions.

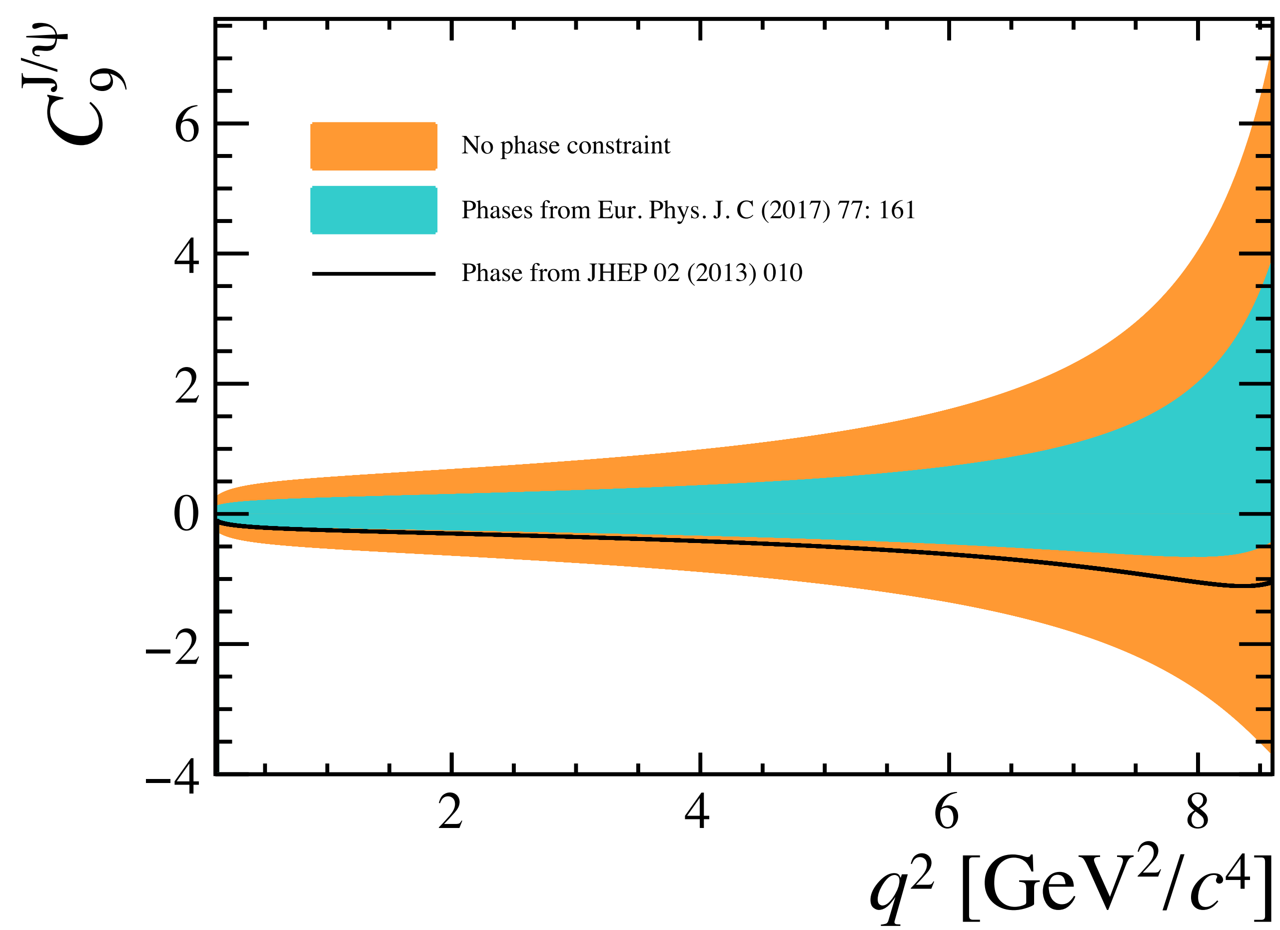
Continuum of broad states above q^2_{max} neglected.

Fit

- Fit to data reveals that the J/ψ has little impact outside the region.

EUR. PHYS. J. C (2017) 77: 161





- Analysis substantially improves precision on J/ψ contribution.

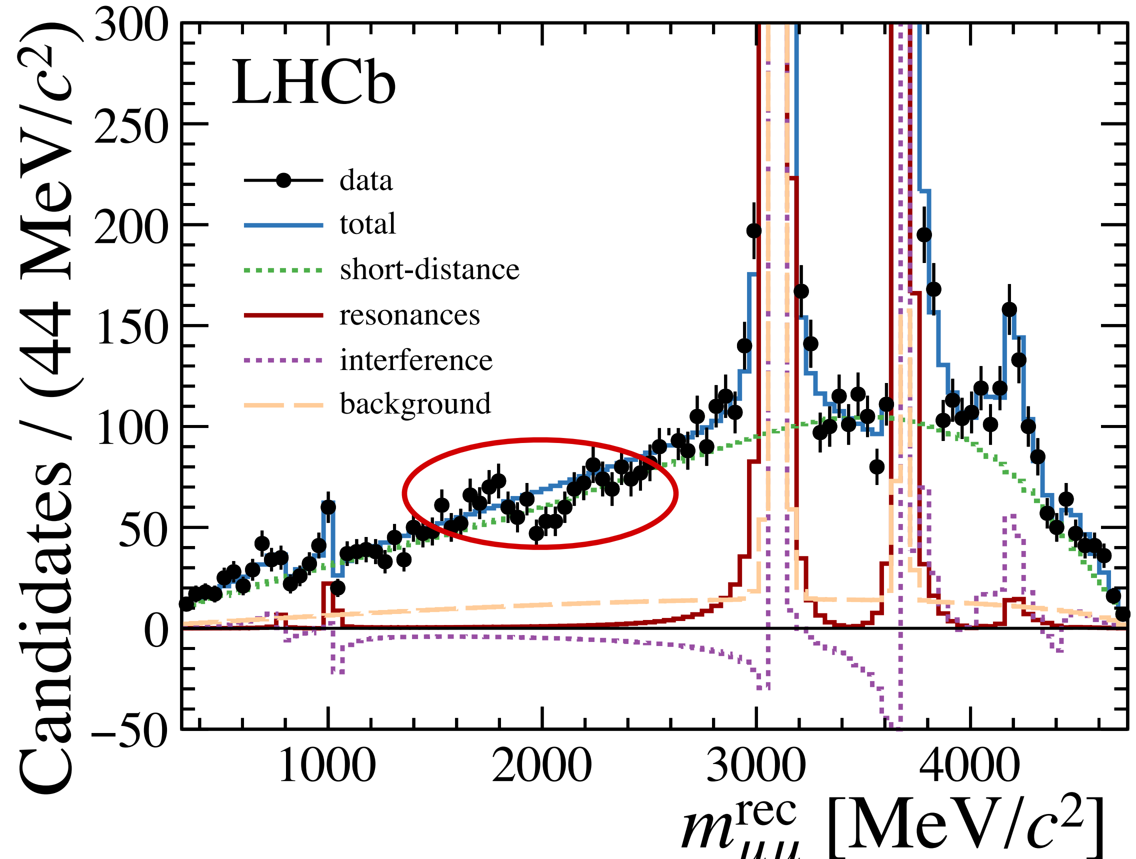
- Non-resonant branching fraction ~3σ below SM …

Other contributions

- There are several things we don't current account for:
    - Broad continuum of heavy cc states
    - Heavier states than the ϕ
    - Other non-resonant contributions (?)

See C. Cornella's talk later in this session.

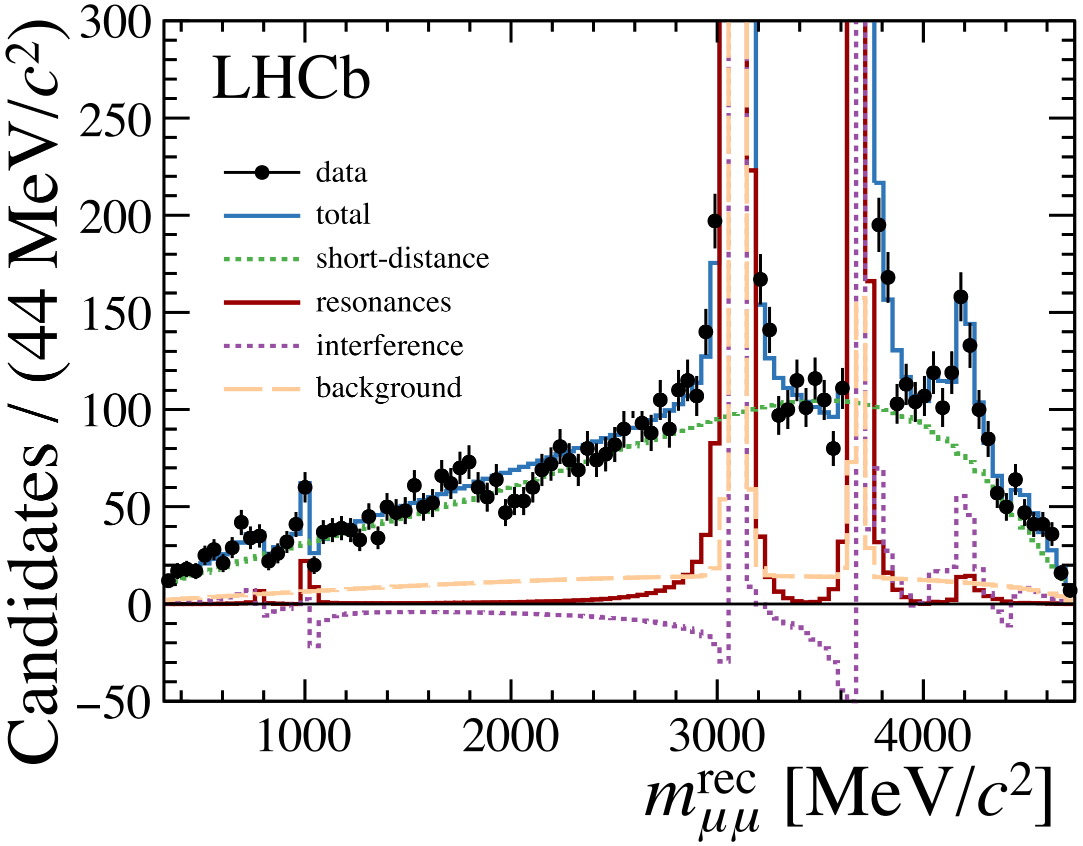
Decay	% of $B^+ \to K^+\mu^+\mu^-$
Penguin	0.6 %
$B^+ \to \rho K^+$	0.0003 %
$B^+ \to \omega K^+$	0.0006 %
$B^+ \to \phi K^+$	0.003 %
$B^+ \to J/\psi K^+$	92 %
$B^+ \to \psi(2S) K^+$	7.3 %
$B^+ \to \psi(3770) K^+$	0.007 %
$B^+ \to \psi(4040) K^+$	~ 0 %
$B^+ \to \psi(4160) K^+$	0.005 %
$B^+ \to \psi(4415) K^+$	~ 0 %

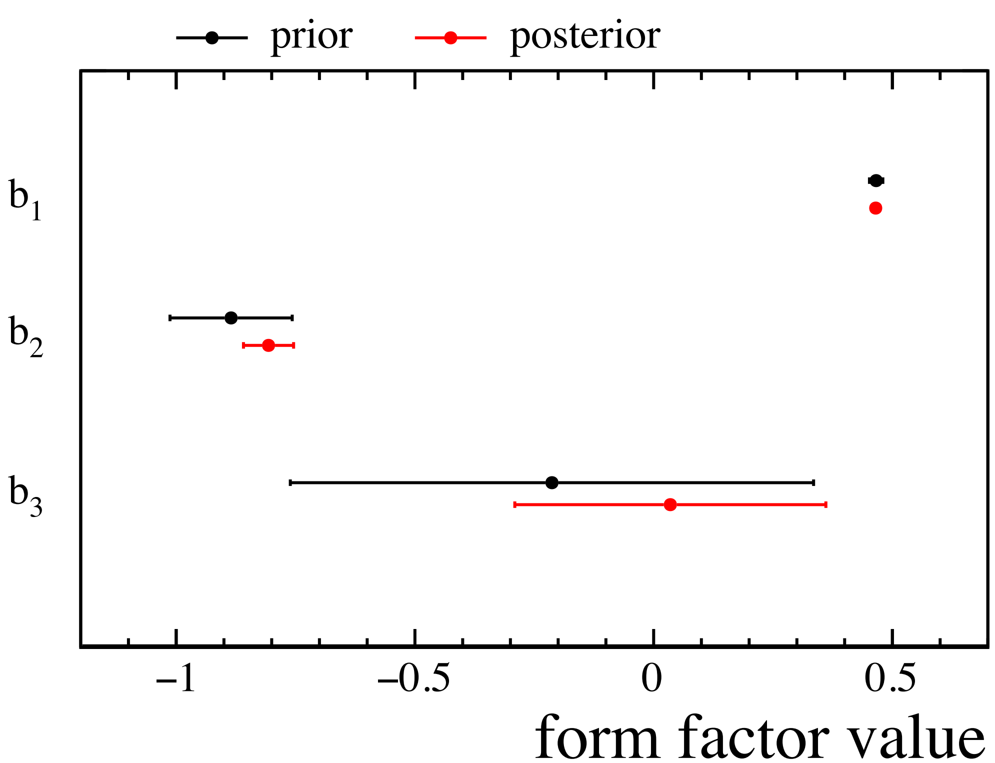


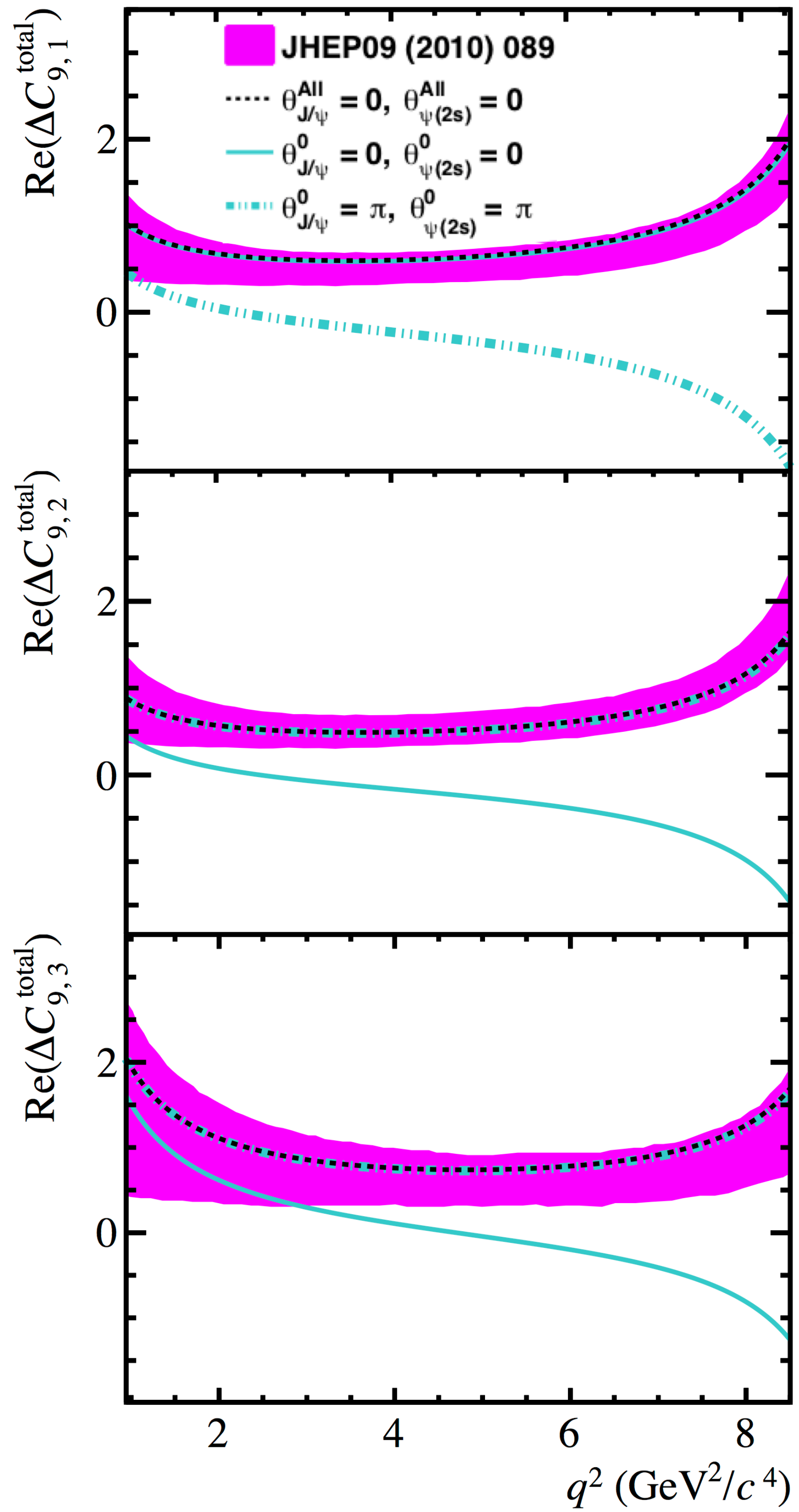
Two useful checks

Blake et al, Eur. Phys. J. C (2018) 78: 453

EUR. PHYS. J. C (2017) 77: 161

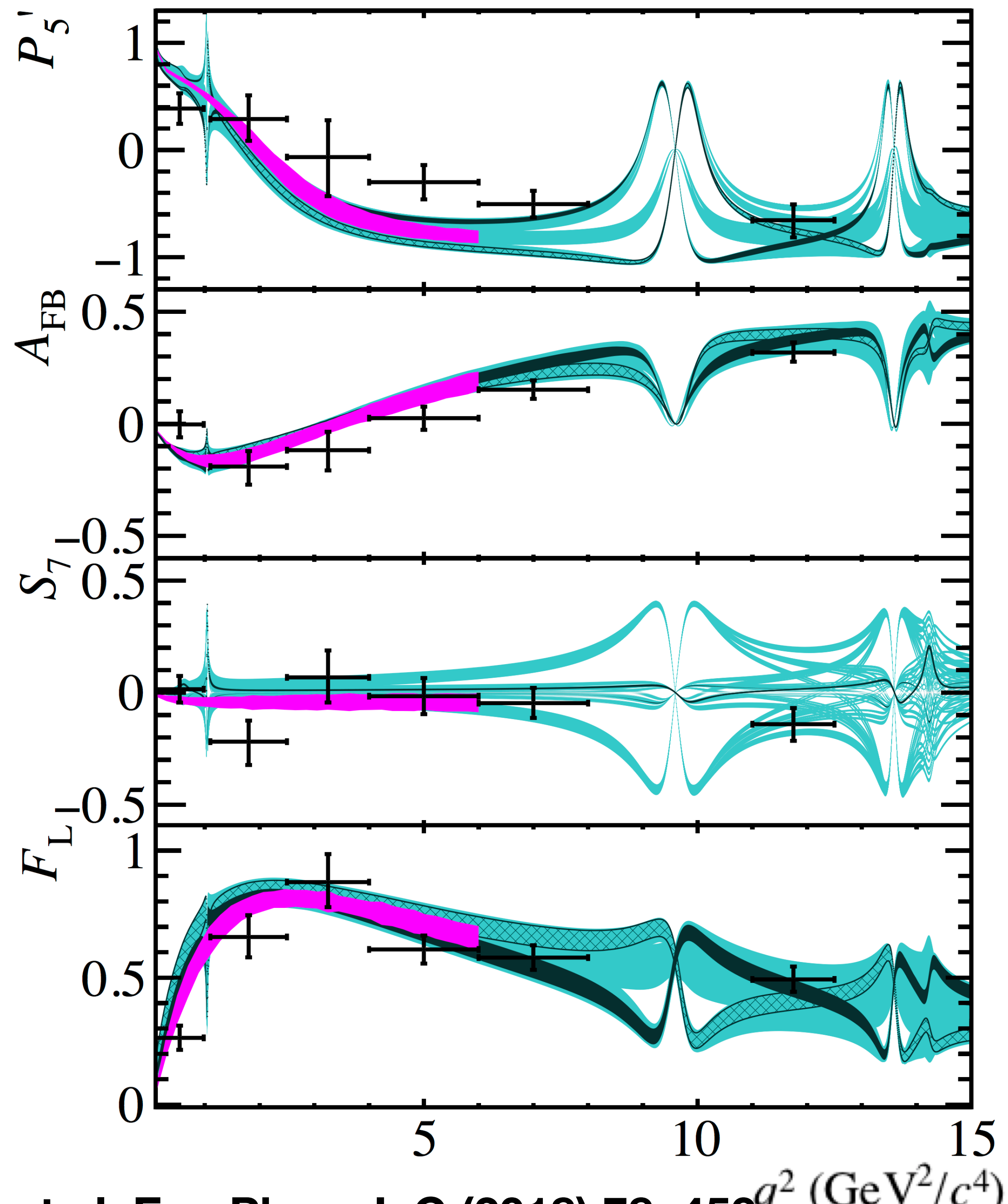






What about K*μμ?

- K*μμ angular observables can also discriminate between different phases.



- With the right phase, J/ψ can explain half the effect in P5'
  - Very important to measure these in the data.
- S7 very sensitive.

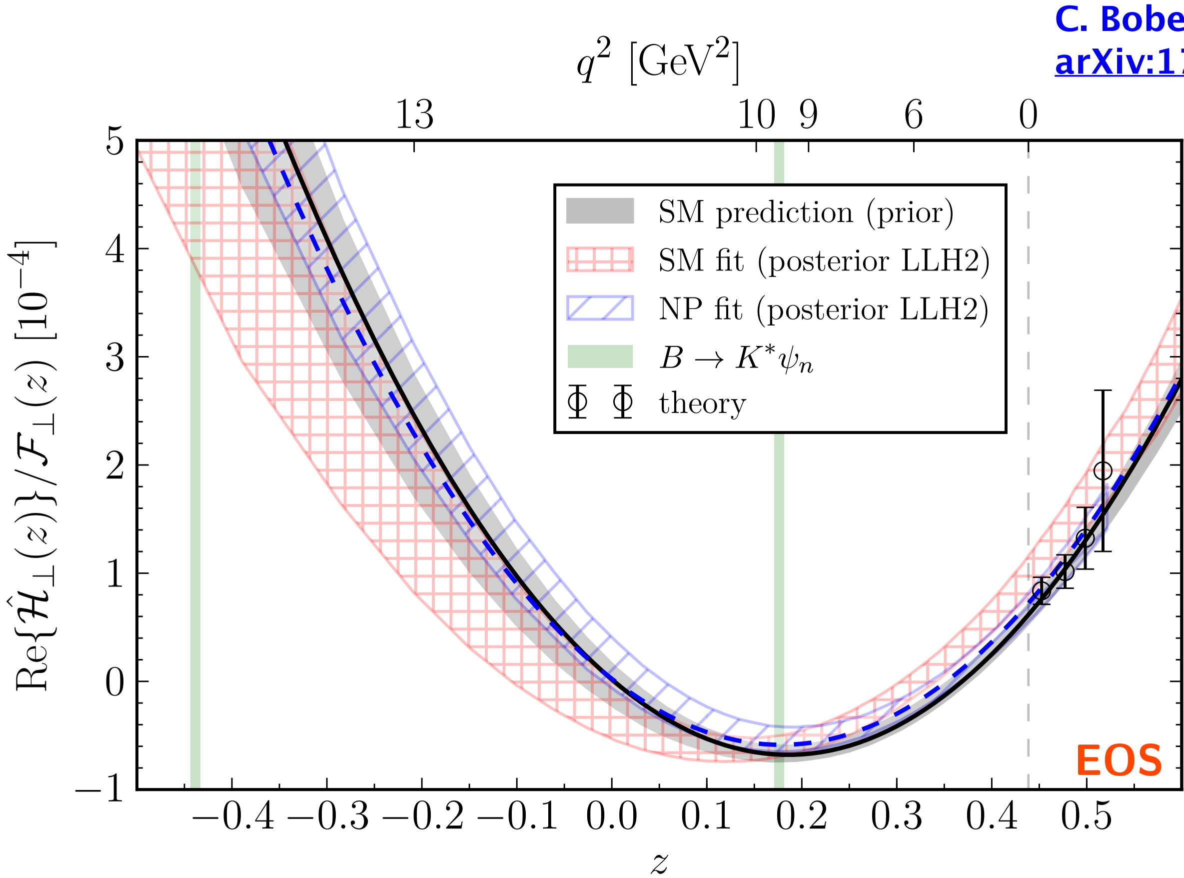
Blake et al, Eur. Phys. J. C (2018) 78: 453

Approach using z-parameterisation

- Calculate the inclusive charm contribution at negative q^2.
- Extrapolate using z-parameterised dispersion relation.

$$\mathcal{H}_\lambda(z) = \frac{1 - z\, z^*_{J/\psi}}{z - z_{J/\psi}} \frac{1 - z\, z^*_{\psi(2S)}}{z - z_{\psi(2S)}} \hat{\mathcal{H}}_\lambda(z) \qquad \hat{\mathcal{H}}_\lambda(z) = \Big[\sum_{k=0}^{K} \alpha_k^{(\lambda)} z^k\Big] \mathcal{F}_\lambda(z)$$

C. Bobeth et al, arXiv:1707.07305

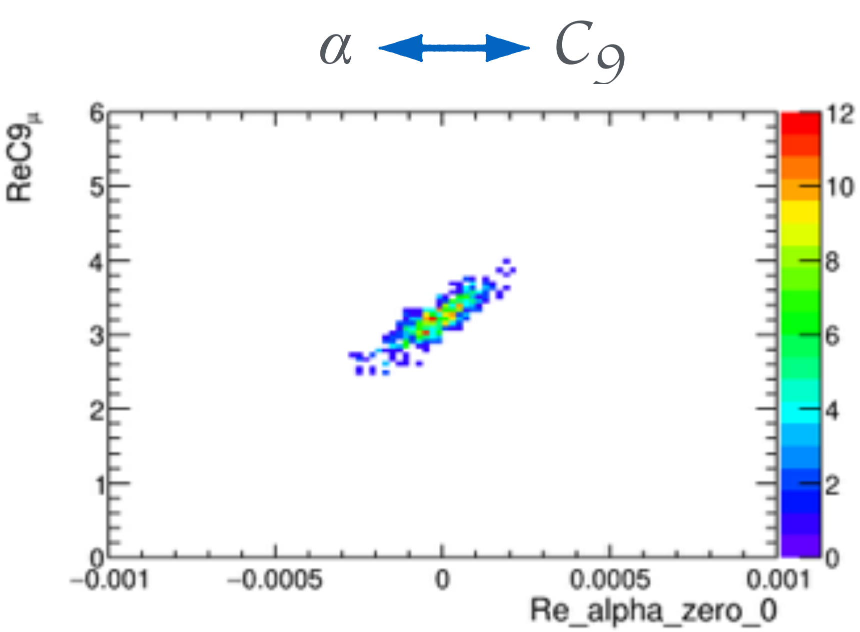


- Fit polynomial to theory points.
- Use polynomial parameters as constraints in fit to data.

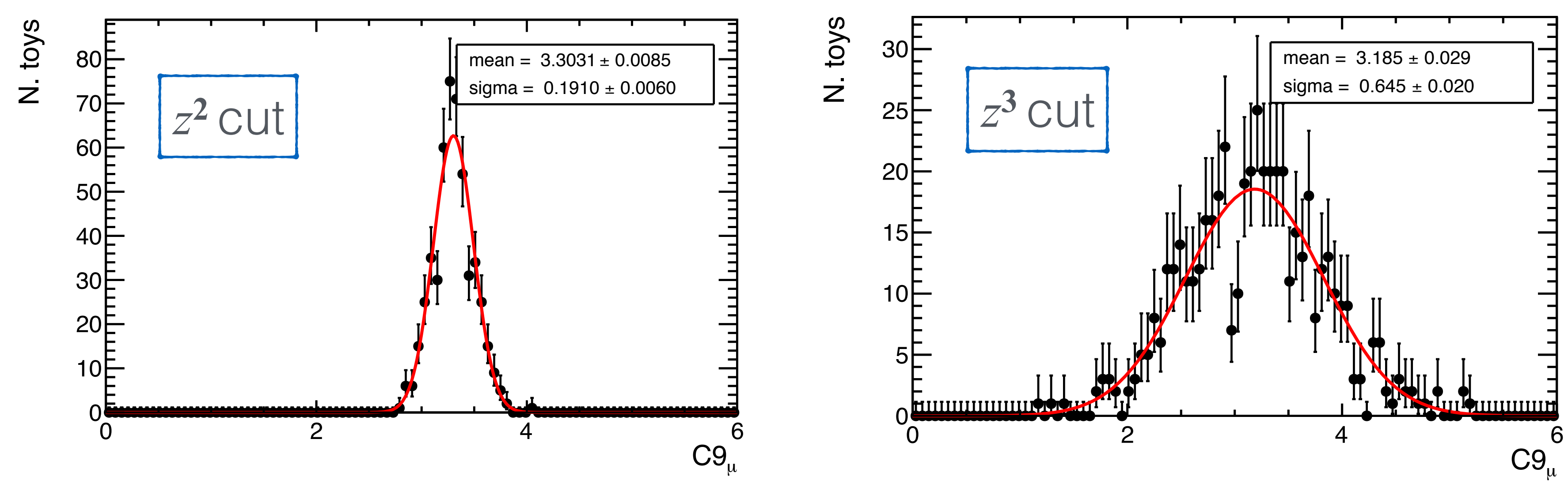
Truncation of the polynomial

- Issue reported at Implications '17 by A. Mauri was that the sensitivity to C_9 was heavily dependent on the truncation of the series.
    - z is not that small and so far has no unitarity condition.

$$\sigma(C_9)\big|_{z^2 \text{ fit}} = 0.19 \qquad \text{and} \qquad \sigma(C_9)\big|_{z^3 \text{ fit}} = 0.69$$



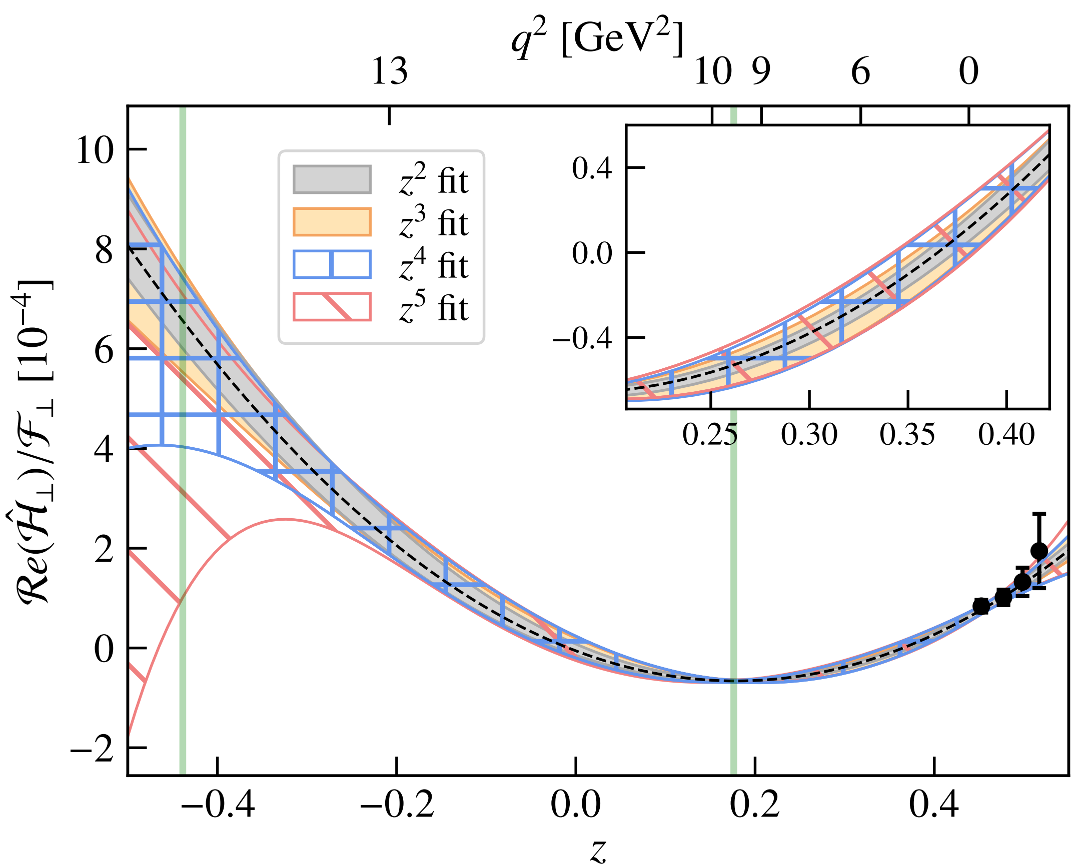
Chrzaszcz et al, arxiv:1805.06378



- However, this was using a staged approached to the data.

Simultaneous fit

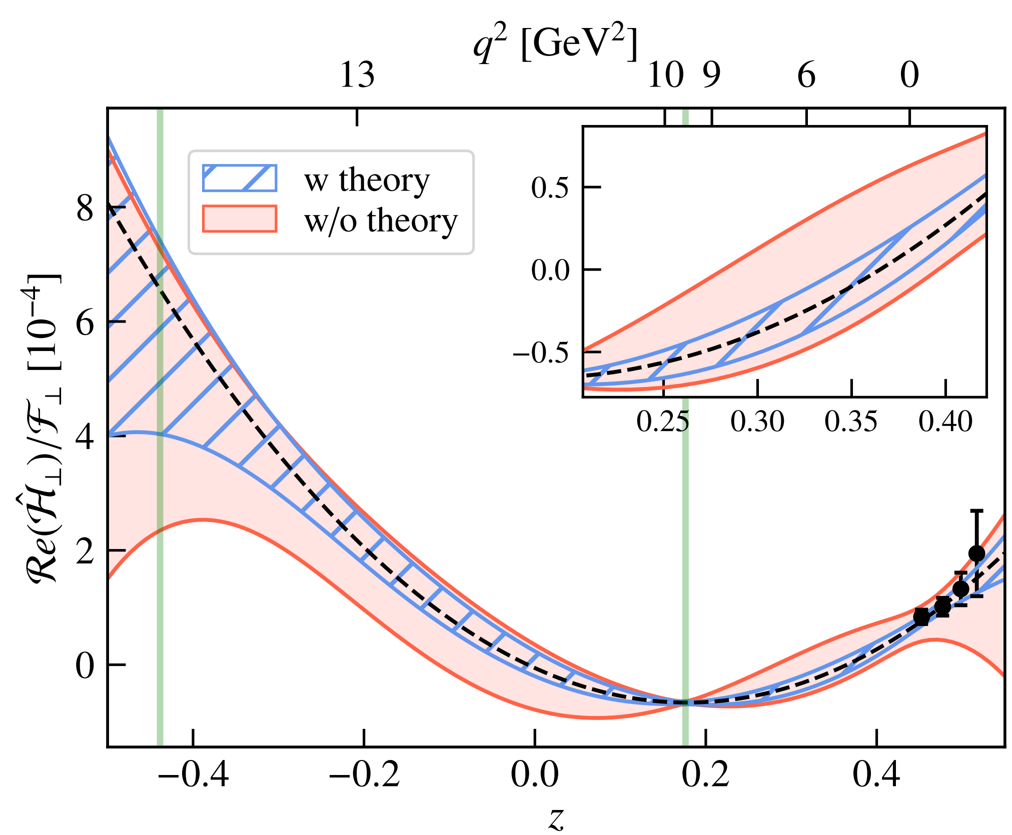
- Simultaneous fit significantly improves situation.



Chrzaszcz et al, arxiv:1805.06378

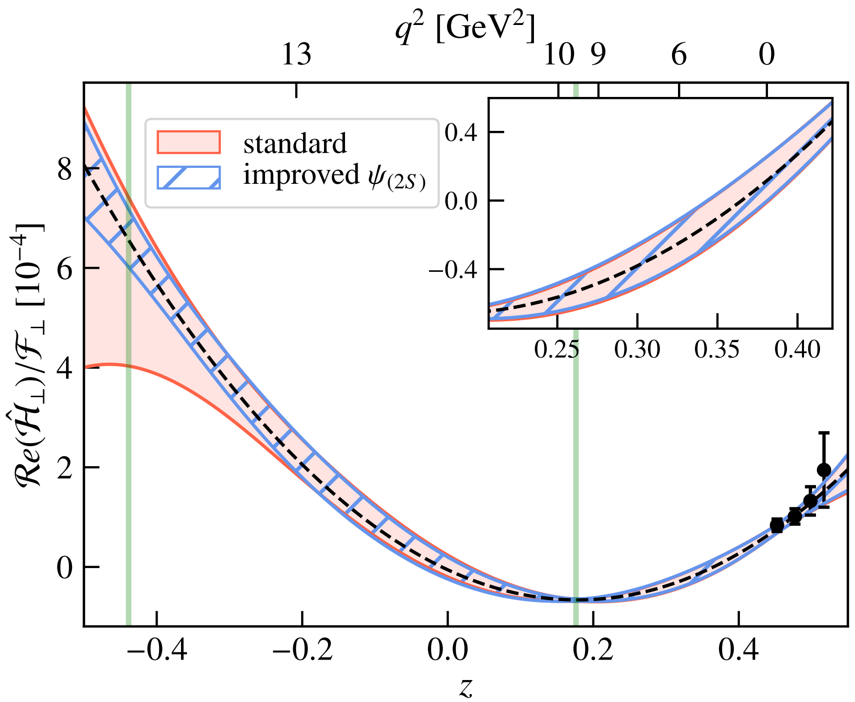
	LHCb Run2		LHCb Upgrade [50 fb^{-1}]	
	Re $\mathcal{C}_9^{NP}$ mean	Re $\mathcal{C}_9^{NP}$ sigma	Re $\mathcal{C}_9^{NP}$ mean	Re $\mathcal{C}_9^{NP}$ sigma
z^2 fit	-0.966 ± 0.006	0.120 ± 0.004	-0.996 ± 0.003	0.060 ± 0.002
z^3 fit	-0.991 ± 0.011	0.217 ± 0.008	-1.015 ± 0.006	0.124 ± 0.004
z^4 fit	-1.022 ± 0.011	0.229 ± 0.008	-1.012 ± 0.007	0.146 ± 0.005
z^5 fit	-0.942 ± 0.016	0.293 ± 0.011	-0.983 ± 0.008	0.157 ± 0.006

- Heavily dependent on theory, but consensus is that these are reliable at negative q².



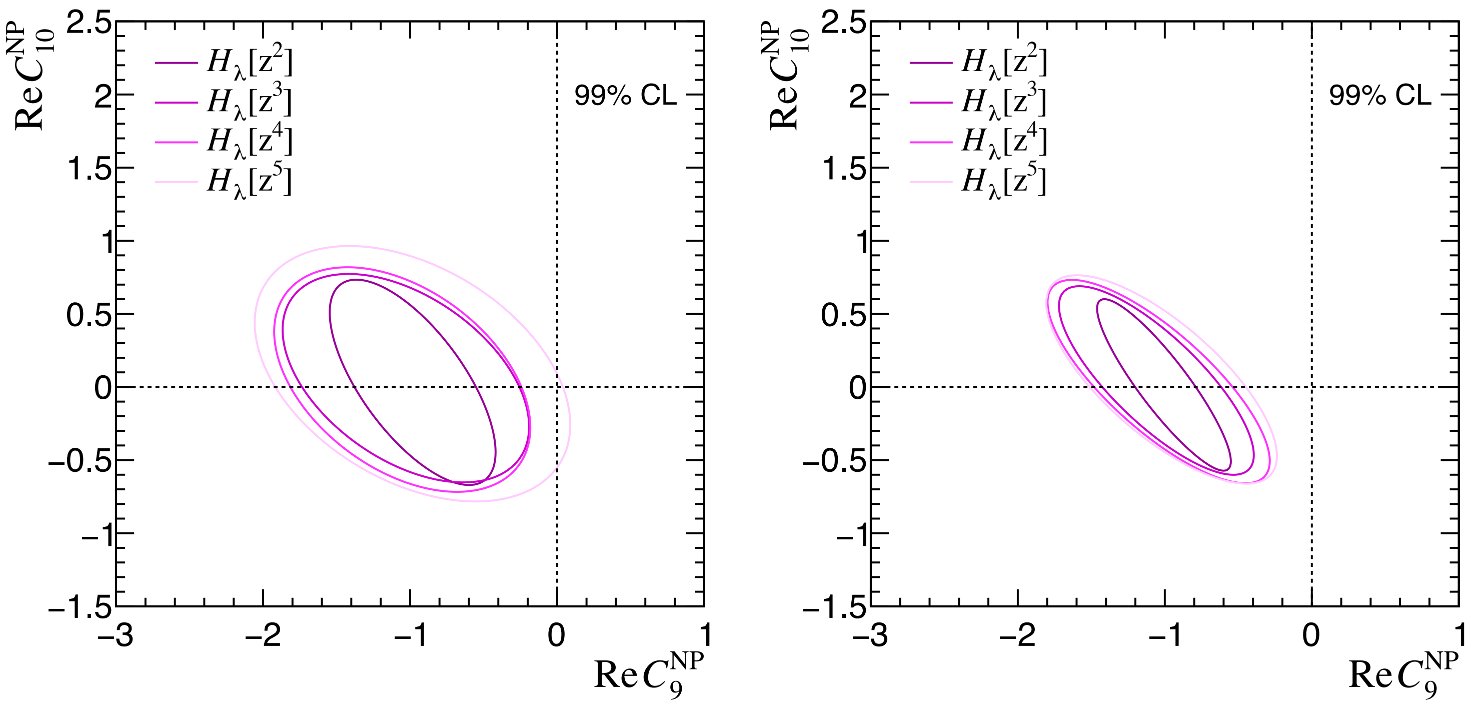
Improvements to external inputs

- Improvement in phase measurements of resonances also useful for high q^2 region.
    - Need a consistent treatment of exotic states between rare/tree-level measurements (something much simpler for the ϕ).



Chrzaszcz et al, arxiv:1805.06378

C_{10} uncertainty also saturates quite soon due to form factor uncertainties.



Plan

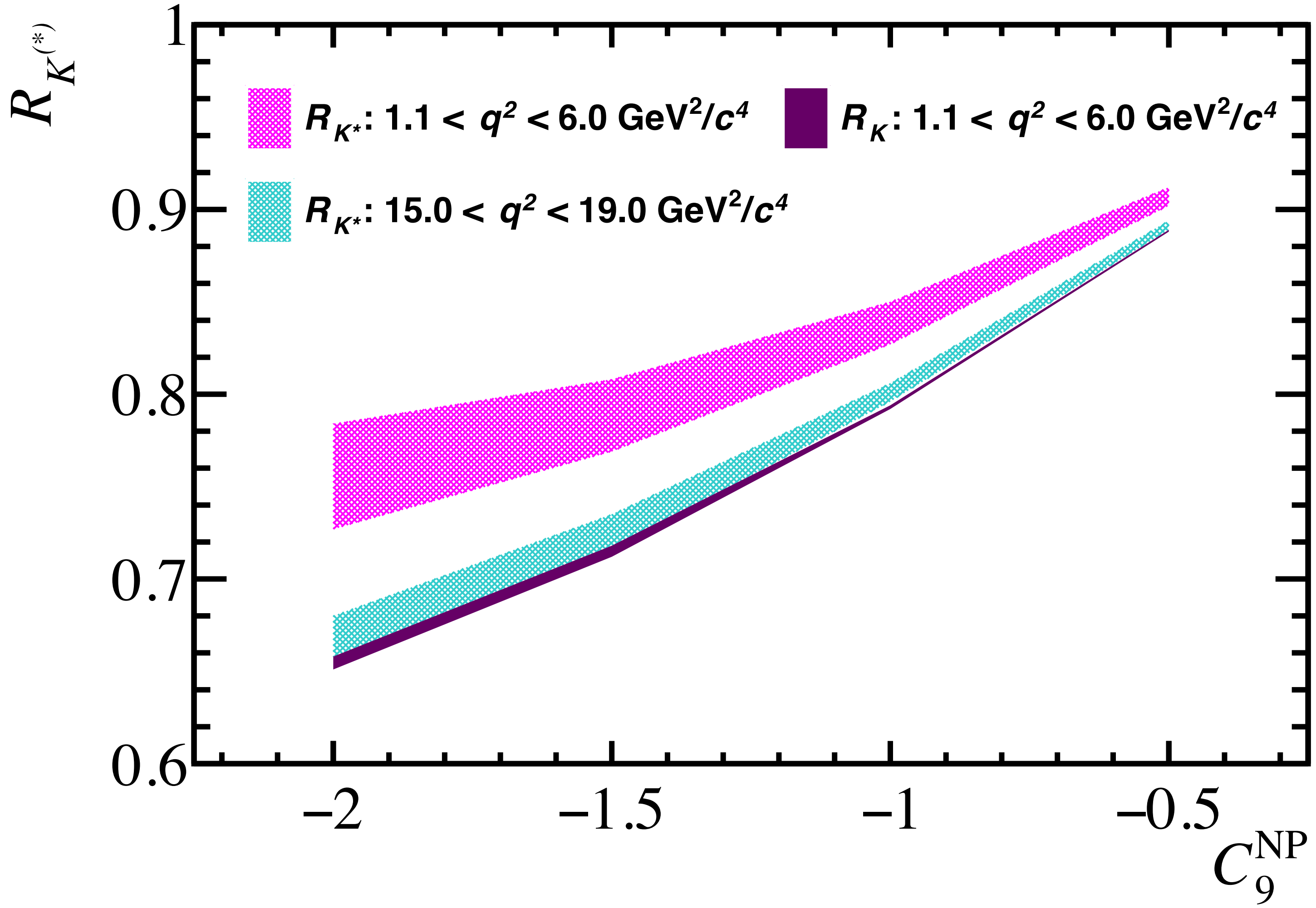
- Unbinned $K^{(*)}\mu\mu$ analyses useful to help disentangle NP from QCD.
  - So far they have not shown any evidence for large charm-loop effects at low q^2.
- Following two approaches, hopefully they get the same value of C_9.
- Challenge to make analyses reanalysable with model improvements.


End

LFU

- Obviously no charm uncertainty on LFU observables in the SM.
  - But NP interpretation can be affected.

Blake et al, arXiv:1709.03921



- Uncertainty not so bad if one can measure spectrum in muon mode.

Analysis assumptions

- Resonances described by Breit-Wigner line shapes, apart from the ψ(3770).

$$A_j^{\rm res}(q^2) = \frac{m_{0\,j}\Gamma_{0\,j}}{(m_{0\,j}^2 - q^2) - i m_{0\,j}\Gamma_j(q^2)}$$

$$\Gamma^{\psi(3770)}(q^2) = \Gamma_1 + \Gamma_2\sqrt{\frac{1-(4m_D^2/q^2)}{1-(4m_D^2/q_0^2)}}$$

$$\Gamma_j(q^2) = \frac{p}{p_{0\,j}}\frac{m_{0\,j}}{\sqrt{q^2}}\Gamma_{0\,j}.$$

$$\Gamma_1 = 0.3\,{\rm MeV}/c^2 \text{ and } \Gamma_2 = 27\,{\rm MeV}/c^2$$

- Wilson Coefficients assumed to be real and no right-handed current counterparts.
- Assume that form factor is common for short- and long- distance.
- No contributions from weak annihilation or resonances with mass > q^2_{max} included.
- No (psuedo-)scalar or exotic contributions considered.

Breit-Wigner

- The Breit-Wigner formulation arises from 3D scattering theory.

$$f = \frac{e^{i\delta}(e^{i\delta} - e^{-i\delta})}{2i}$$

$$= e^{i\delta} \sin\delta = \frac{1}{(\cot\delta - i)}$$

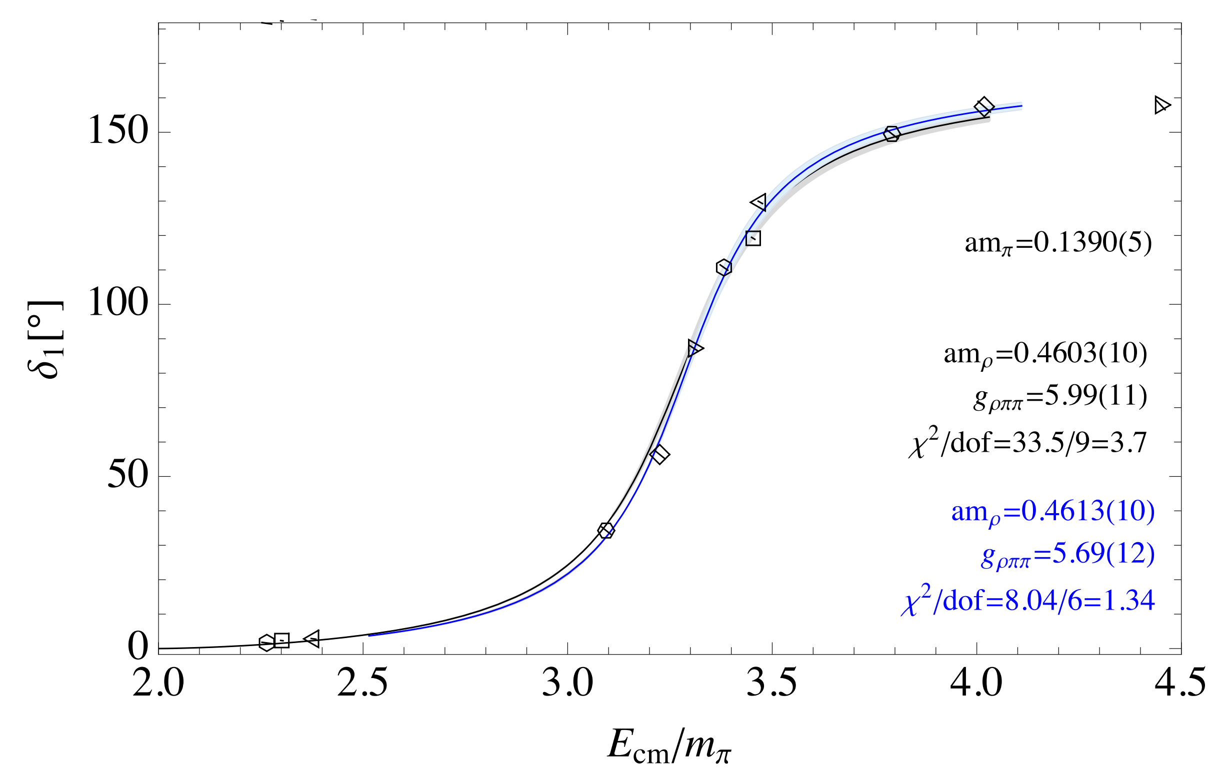
$$\cot\delta(E) = \cot\delta(E_R) + (E - E_R)\left[\frac{d}{dE}\cot\delta(E)\right]_{E=E_R} + \cdots$$

$$\simeq -(E - E_R)\frac{2}{\Gamma},$$

Introduction to high energy physics, Perkins

Provided $|E - E_R| \approx \Gamma \ll E_R$

Guo, Alexandru, Molina, Doering,Phys. Rev. D 94, 034501 (2016)



- Perhaps Lattice can check the J/ψ as well.

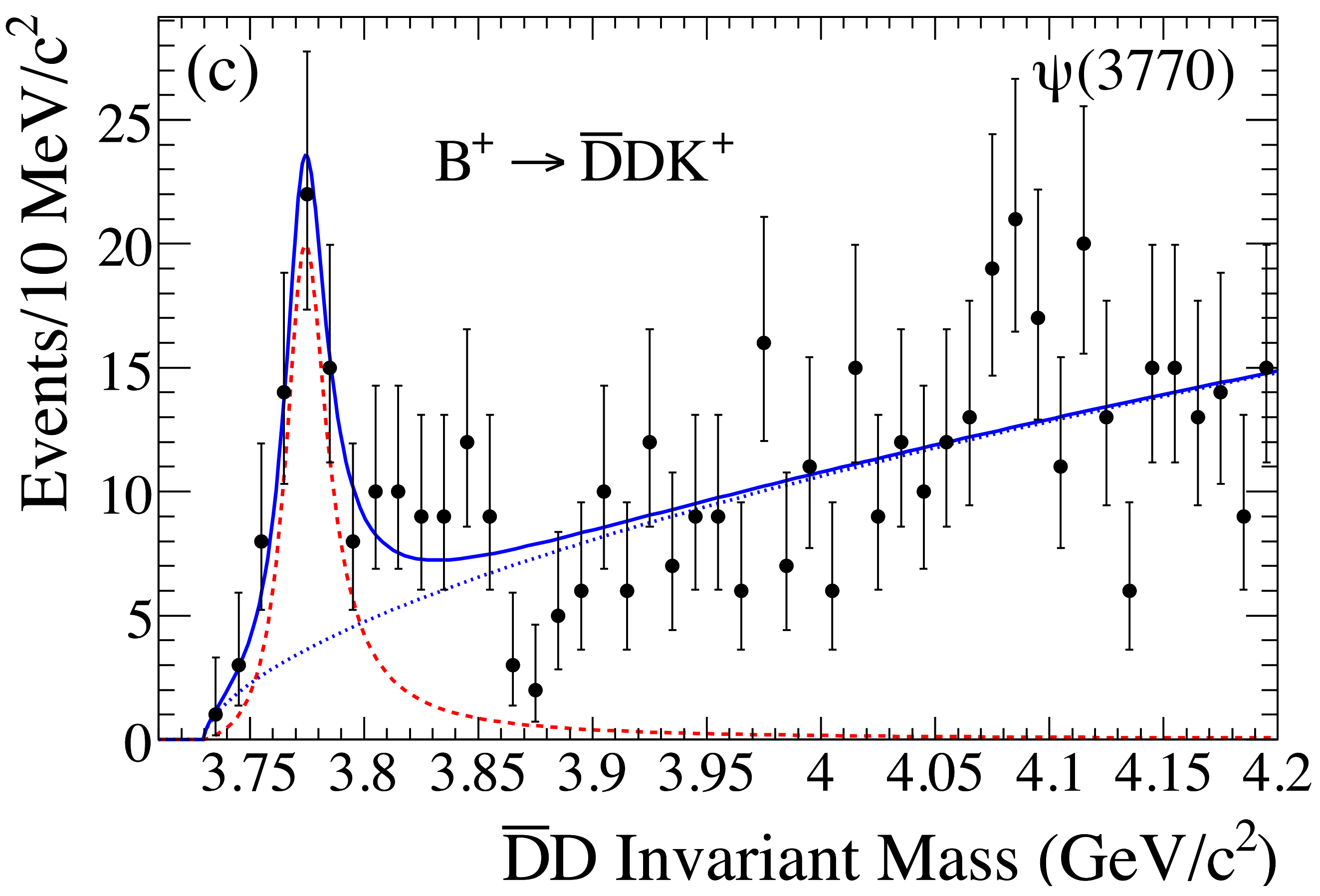
- The broader resonances at high q^2 more affected, but less data there.

- We are really worried about tail of the tail.

Fully hadronic input

- Huge samples of B—>D$^{(*)}$D$^{(*)}$K expected at Belle 2 and LHCb upgrade 2

From BaBar, Phys.Rev.D77:011102,2008



- Can these help fill in the gaps of missing components?